Renewable and Sustainable Energy Reviews 13 (2009) 1504–1512

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The development and application practice of wind–solar energy hybrid generation systems in China

Li-qun Liu [a,b,*], Zhi-xin Wang [a]

[a] Department of Electrical Engineering, Shanghai Jiao tong University, 200240 Shanghai, China
[b] Department of Electronic and Information, Taiyuan University of Science & Technology, 030024 Taiyuan, Shanxi Province, China

ARTICLE INFO

Article history:
Received 23 June 2008
Accepted 29 September 2008

Keywords:
Solar energy
Wind energy
Hybrid generation system
Application practice

ABSTRACT

China is the largest developing country in the world. At present, more and more energy demand gives immense pressure to Chinese government. The inappropriate energy structure must be improved by Chinese government in order to achieve the sustainable development of economy and society. Development and application of renewable energy, such as wind energy, solar energy, biomass energy, etc., have been regarded by the government and the local people in the past 10 years, and more and more actual examples have been established, which are supported by government and plants in China. It is well known that there are abundant wind and solar resources in China. This paper presents the distribution zone and development and application practice status in China. However, a common drawback is existing in the stand-alone wind energy and solar energy generating power system, which is the unpredictable output electric power, and the output power depends on the unpredictable weather and climatic changes. Fortunately, the wind–solar hybrid generation system can partially overcome the problems. The conventional structure and key technology of stand-alone wind–solar hybrid generating system, the current status and outlook of wind–solar hybrid energy system are presented in the paper, for example, the city road lighting system, distributed generation, photovoltaic (PV) water pumping for irrigation, etc. At the end, the policies and laws of China central government and local governments are described, and the development barriers and recommendations are introduced.

Contents

* Corresponding author at: Department of Electrical Engineering, Shanghai Jiao tong University, 200240 Shanghai, China. Tel.: +86 21 34201448.
E-mail address: llqd2004@163.com (L.-q. Liu).

1364-0321/$ – see front matter.
doi:10.1016/j.rser.2008.09.021

1. Introduction

China lies in the northeastern part of East Asia between 4° and 53° North latitude and 73° to 135° East longitude with an area of 9.6 million km^2, and a population of about 1.3 billion. The Pacific lies in the east of China. The coastal zone of China consists of about 18,000 km. The southeastern coastal zone of China is the most developed economy zone, which inhabit more than 60% of Chinese people. The largest patch of serious desertification lies in the west of China, where is the homestead of millions of rural population, and the economy of west zone is poorer compared with coastal zone. But there is abundant natural resources deposit in the large west area.

The industrialization of Chinese society is on rapid development in every nook and corner, and the growing pressure of increasing population adds to the stress on natural resources, including land, water and air. The need for oil, natural gas and electric power are rapidly increasing with the development of Chinese society. According to the reports given by Chinese Development and Innovation Committee (CDIC), the total amount of oil dosage in 2007 was 0.35 billion ton, which ranks the second in the world and just behind America [1]. The rapid developing economy needs the import of fossil fuels, particularly oil, on a large scale. Based on the CIQ data, the amount of imported oil in 2007 was 0.16 billion ton [2]. The total amount of coal dosage in 2007 was 2.523 billion ton, which ranks the first in the world [3]. The total amount of SO_2 emission in 2005 was more than 20 million ton, which ranks the first in the world [4]. Many environmental problems, including air pollution, soil pollution, water pollution, acid precipitation, are all related to inappropriate energy structure of China to some extent. Moreover, too much reliance on imported oil is critical from energy security point of view. For a long time, the energy generated by using the coal plays a dominant role in China. The percentage of coal in primary energy production and consumption is more than 70% [5]. The renewable sources, i.e. solar, wind, tide, biomass, etc., occupy a very small percentage in the whole energy structure.

Because of fast-growing economy and population, the demand of energy is rapidly increasing, more and more cities in China face the energy lack and environmental pollution. Today, China has become the third economic system in the world, and is the largest developing country in the world at the same time. The energy and environmental questions in China have great effects on the world economic sustainable development. Based on the status, the Chinese government has realized the importance of energy and environmental questions. The Chinese government established the Renewable Energy Law in February 2005 to act as the guarantee and to lay a special emphasis on the subject of renewable energy development [6]. The adjusting energy structure and improving energy utilization efficiency are executed in the entire China. Currently, the renewable energy is applied to many domains in developed, and developing nations, the renewable sources are expected to play an important role in total electrical energy demand, and the renewable energy sources, such as solar, wind, biomass, etc., have gained a lot of attention because they are renewable, friendly to the environment, easy for distributing abroad, and flexible for installation. And more and more specialists of China realized the fundamentality of the renewable sources. The Chinese government has spent enormous money and energy in the renewable source domains in order to achieve the sustainable development in economy and society. But the renewable sources have some problems in that it is impossible to afford enough electric power alone, i.e. the density electric power of renewable sources are very low, and the stability is bad. The output electric power from renewable sources is always changing with weather conditions. The combined powers of multifold renewable sources have been researched in some countries, and which is used in the remote villages and for city lighting system and water pumping for irrigation or desalination purposes, i.e. wind–diesel hybrid, solar–diesel hybrid, solar–wind hybrid, etc. The combined system of the solar energy and wind energy was called the photovoltaic and wind energy hybrid systems to supply enough electric power. The solar–wind hybrid system is possible to achieve much higher generating capacity factors and reliability by combining wind turbine with photovoltaic generators to overcome the fluctuations in plant output under various weather conditions. Chinese specialists consider the solar–wind hybrid system to act as an important role. More and more solar–wind hybrid projects are being established in hundreds of Chinese cities, and the projects are encouraged by the government policy.

This article will discuss the current status of energy structure in China. The following sections describe the distributing zone and applications of solar energy and wind energy in China. Then the application status and outlook of wind–solar hybrid energy system is discussed. Finally, the policy of central government and local governments and barriers and recommendations are introduced in this paper.

2. Current energy structures in China

Fig. 1 shows a graphical representation of Chinese primary energy supplies. Chinese energy admixture is highly dependent on fossil fuels, i.e. coal, oil, natural gas and other. Coal energy has a share of 69.4% in 2006, which is the most important fossil fuel in China. Renewable energy and nuclear energy has a share of 7.2%. Oil energy has a share of 20.4% and the remaining 3% is supplied by natural gas. The energy structure is very inappropriate to sustainable development. The high dependence on fossil fuels has a huge negative impact on economy and energy security and environment of the country. Fig. 2 shows a graphical representation of Chinese primary energy supplies in past 30 years. As shown in Fig. 2, the economy and the demand of energy are rapidly increasing in the past 30 years, but the inappropriate energy structure of China is hardly changed [5].

In China, there is a very big fossil fuel resource, and abundant natural resources deposit in the large area. The energy need of China is very big with the development of economy at the same time. According to the data of Chinese Development and Innovation Committee in 1999, Fig. 3 draws a comparison between the Chinese reserves of primary energy and the world reserves of primary energy. As it can be seen from Fig. 3, the reserves of Chinese coal energy is the most important fossil fuel in China, but the reserves can only be exploited for about 105 years, simultaneously with the world coal energy can be exploited for about 216 years. The oil energy of China can be exploited for about 15 years; the world oil energy can be exploited for about 45 years at the same time. Natural gas energy can be exploited for about 30

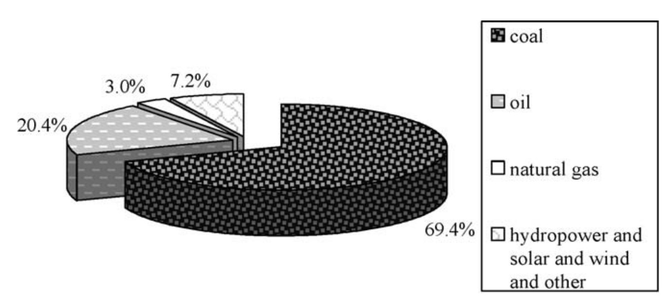


Fig. 1. Primary energy supplies by resource in 2006 (source: CDIC, 2006).

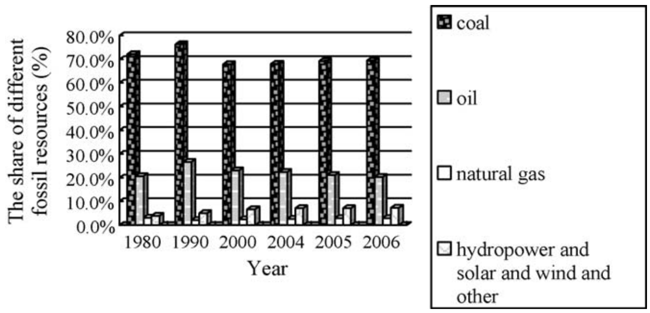


Fig. 2. Primary energy supplies by resource in the past 30 years (source: CDIC, 2006).

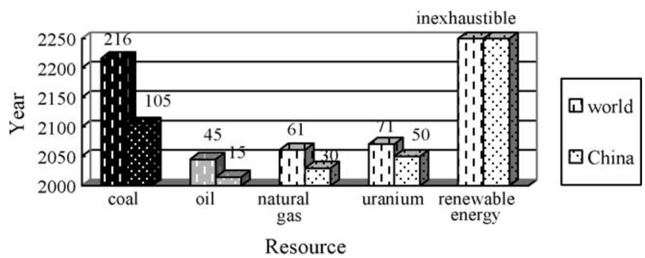


Fig. 3. Draw a comparison between the Chinese reserves of primary energy and the world reserves of primary energy in 1999 (source: CDIC, 2006).

years and the uranium resource can supply for about 50 years in China, simultaneously with the world natural gas energy and the world uranium energy are 61 years and 71 years, respectively. To draw conclusion, the energy impact of China is very austere than the impact of world, and the impact of economic and society sustainable development is austere in the future [6].

3. Chinese renewable energy situations

China has a big need of electric energy with the rapid economy development, but the reserves of fossil fuels are impossible to sustain the sustainable development in the future. A new energy must be found in order to sustain the sustainable development. As shown in Fig. 3, the renewable energy sources are expected to play an important role in the future because they are renewable, friendly to the environment, easy to distribute abroad. The renewable energy sources have gained lots of attention by the Chinese government and specialists in the past 10 years, such as solar, wind, biomass, etc.

3.1. Wind energy

China has abundant wind energy resources in large zone, the total amount of wind energy resources are 3.2 billion kilowatt under the height of 10 m conditions, of which about one billion kilowatt can be effectively utilized. Four wind energy zones are divided according to the wind speed, which is indicated in Table 1.

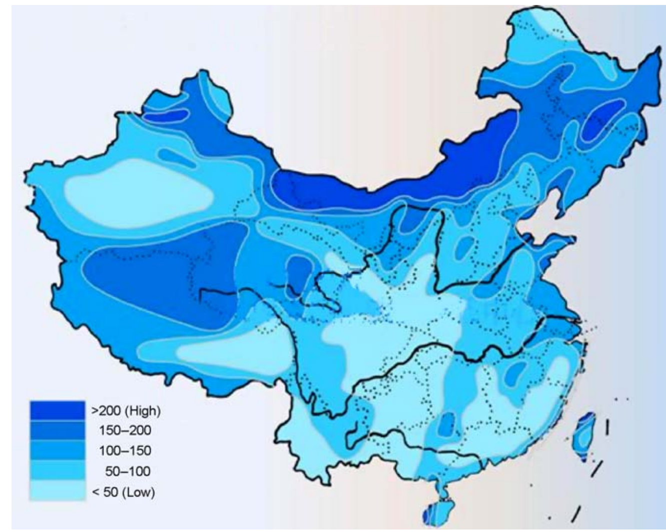


Fig. 4. The statistics of wind energy density in 2008 (source: CWB, 2008).

According to various wind speeds, Fig. 4 shows five wine energy zones. According to the data of literature [7], Table 1 shows the wind energy distributing zone and the share percent of country area in China. As shown in Table 1, China has abundant wind energy sources in broad country, the wind energy can be utilized in more than 75% of country area, the accumulative total hours when wind speed $\geq$3 m/s is more than 2000 h, and the wind energy density is more than 50 W/m^2. The best abundant zone has a share of 8%, which is the best wind energy zone in China, such as southeastern coastal zone, Tibet province. The deficient zone of wind energy is less than 25% of country area, such as Sichuan and Guizhou and Yunnan province. The better abundant zone has a share of 18% and the remaining 50% is available zone. According to the data of Chinese weather bureau (CWB), the statistics of wind energy density in China is shown in Fig. 4. The unit of wind energy density is W/m^2, and the statistics data are corresponding with the Table 1 [8–11].

Wind energy application of China goes back to thousands of years, which is utilized to replace or augment human and animal muscle power by our ancestors, i.e. water pumping for irrigation, grind grain, and navigation. The small size and stand-alone wind power generating system is utilized for the remote villages and a pasturing area in China, but the wind energy has not been regarded for a long time. Until the late 20th century, Chinese government and people realized that the wind energy is significant to play an important role in total electrical energy demand. At present, the small size and stand-alone wind power plants, wind-pumps and windmills are being successfully operated in many remote villages and city lighting system. The remote village's electric power supply is implemented by using wind energy, and the number of people in remote villages are about 600 thousands.

The big wind energy generating technology was improved step by step since the early 1970s in the developed countries, such as

Table 1
The wind energy distributing zone and the share percent of country area.

Wind energy index	Best abundant	Better abundant	Available	Deficient
Wind energy density (W/m^2)	>200	200–150	<150–50	<50
Average wind speeds (m/s)	6.91	6.91–6.28	6.28–4.36	<4.36
Accumulative total hours when wind speed $\geq$3 m/s	>5000	5000–4000	4000–2000	<2000
Accumulative total hours when wind speed $\geq$6 m/s	>2200	2200–1500	<1500–350	<350
The share percent of country area (%)	8	18	50	24

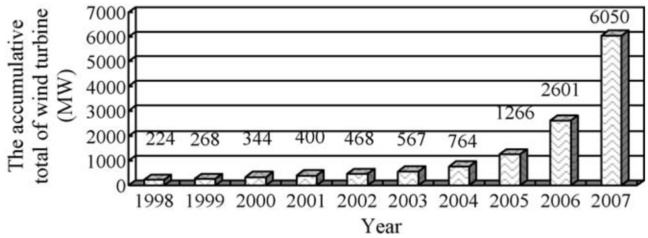


Fig. 5. The accumulative total of wind energy generating system in the past 10 years (source: CWEA and news, 2008).

Denmark and Germany. For instance, the share of wind energy generating system is more than 20% in Denmark, and the share will be increasing step by step in the whole energy structure, which is expected to achieve 50% in 2030. China has spent enormous money and energy in the wind sources domain, the wind capacity has doubled approximately every year in the past 5 years. Based on the data of Chinese Wind Energy Association (CWEA) and news, Fig. 5 shows the accumulative total of wind energy generating system in the past 10 years [12–16]. During the last decade of the 20th century and the beginning of new century, the development speed of wind energy is smooth. An obvious increasing speed is shown in Fig. 5 since 2005, and the new wind capacity is 3449 MW in 2007, which ranks third in the world and just behind America and Spain. The accumulative total amount of wind capacity in 2007 is 6050 MW, which ranks fifth in the world [16]. In the past 10 years, the share of wind energy is increasing in the whole generate electricity system and new generate electricity system. As shown in Fig. 6, the share of wind energy is obviously increasing in the total of new generate electricity system, which is increasing from 0.24% to 3.7%, and the share is increasing from 0.08% to 0.85% in the whole generate electricity system. As mentioned above, the data indicated the Chinese government's decision to improve the inappropriate energy structure [17]. The accumulative total of electric energy in 2005 is more than 0.5 billion kW, and the share of wind energy is of 0.02%. Chinese government expects that wind energy will share 10% of the primary energy supply in 2020, and the object capacity of wind turbine is 30,000 MW in 2020 [18–24]. At present, the biggest wind electric field group in China is being built in Jiuquan of Gansu province, and the accumulative total of wind electric field is 12,710 MW in 2015, and the whole invest is more than 15 billion dollars [25]. The biggest wind electric field in China lies in Huilai of Guangdong province, which has generated electric power, and the capacity of Huilai wind field is 100 MW [26]. Certainly, abundant wind energy was distributed in the Chinese far-flung sea line, and some local governments regard the exploitation of sea breeze. The first wind electric field on the sea in China is east sea bridge project, which has invited public bidding, and the total capacity will be 100 MW in 2009 [27]. The role of wind energy is important, and the market of wind energy is big in the future.

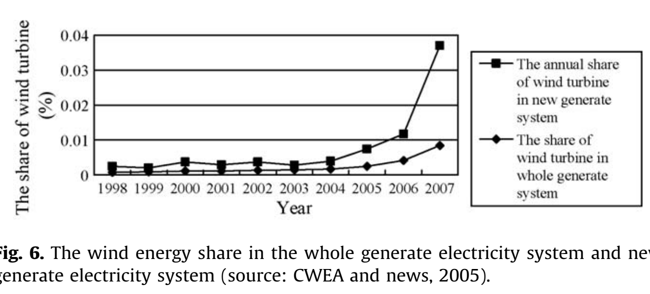


Fig. 6. The wind energy share in the whole generate electricity system and new generate electricity system (source: CWEA and news, 2005).

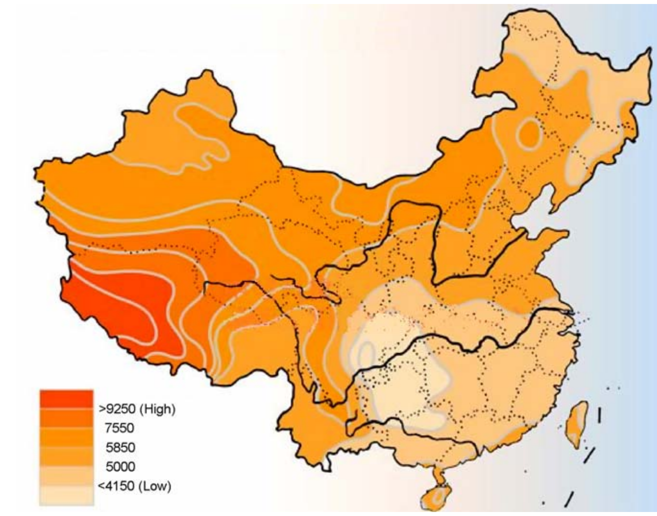


Fig. 7. The statistics of solar energy density in 2008 (source: CWB, 2008).

3.2. Solar energy

China lies in the northeastern part of East Asia between 4° and 53°North latitude and 73° to 135° East longitude with an area of 9.6 million km^2. According to the data of Chinese weather bureau (CWB), the statistics of solar energy in China is shown in Fig. 7. Here, the unit of solar energy is MJ/m^2 *a*. As shown in Fig. 7, the total solar energy resources are enormous in large soil area, but the irradiation is various in different zones. The Tibet and southeast of the Qing-zang altiplano lie in the highest irradiation zone of solar energy, and the irradiation is decreasing with the longitude increase. Six solar energy zones are divided according to the solar energy radiation quantity, which is indicated in Fig. 7. According to the data of Chinese development and innovation committee in 2006, the abundant zone of solar energy has a share more than 67%, which is the comparative efficient zone of solar energy application in China, and the sunlight hours is more than two thousands, and the annual total amount of irradiation is more than 6 billion MJ/m^2 [28–31].

The first application of solar energy in China goes back to 1971, which is utilized to the power supply of secondary planet by Chinese scientist. In the past 30 years, there are many applications for the direct and indirect utilization of solar energy, and the application zone of solar energy is rapidly increasing with the development of China, i.e. solar energy building, water heater, navigation marker and road lighting system, and the most extensive utilization is solar water heater, which is broadly utilized to every community in China, and the new total amount of solar energy water heater in 2005 has a share of 77.3% in the world. As shown in Fig. 8, the accumulative total amount of solar energy water heater in 2005 has a share of 63.1%, and China has become the biggest solar water heater production, sale and holding country in the world. The above data are based on 21st century Renewable resource policy network (REN21). Especially, with the rapid increase in the energy price, solar energy water heater has better competition and is more popular compared with conventional gas combustion and electric-driven water heaters [32,33].

Chinese government and people in 21st century realize that the solar energy is significant to play an important role in total electrical energy demand. At present, the small size and stand-alone solar energy plants are still main utilization form, i.e. solar-pumps and solar-light are being successfully operated in many remote villages and city lighting system, and many west villages'

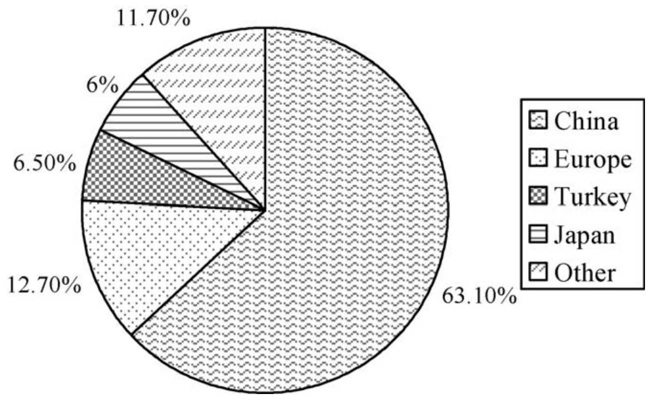


Fig. 8. The accumulative total amount of solar energy water heater in 2005 (source: REN21, 2006).

electric power supply is implemented by using solar energy. As shown in Fig. 7, there are so many Gobi and desert in west China, where they have very high irradiation and large no man's land. The large-scale power grid line desert PV power station is the main trend of PV power development in future.

According to the data of news, the total yield in China of solar cell in 2007 is 1200 MW, and the share of solar energy is of 35% in whole world, which ranks first in the world [34–36]. Based on the data of CDIC and news, Fig. 9 shows that the yield of solar cell has rapid increased in the past 8 years. But a fact is shown from the date of CDIC, the accumulative total amount of PV power generation capacity in 2005 is less than 70 MW, and the share is less than 0.0002% in the whole electric energy system [37]. Until 2007, the accumulative total amount of PV power generation capacity in 2007 is less than 110 MW, and the new PV capacity is 25 MW [39]. Simultaneously, the development of solar energy can help the Chinese government to improve the inappropriate energy structure, and Chinese ordinary people are more and more considered to the renewable energy. The hortative policy of solar energy application is constituted by the Chinese government. Chinese government expects that photovoltaic generation will achieve 300 MW in 2020, and which will achieve 1.8 GW in 2050, and which has the share 5% of the primary energy supply [38]. Based on the foregone experience, the development speed of solar energy generation in China is more than the expected speed. According to the data of new photovoltaic industry bulletin in 2007, the photovoltaic generation capacity is 300 MW in 2010, and which will achieve 1.8 GW in 2020 [39]. At present, the biggest photovoltaic plant is established in Shilin of Yunnan province. The capacity and the investment are 66 MW and 0.6 billion dollars, respectively [40]. Consequently, the market and development potential of solar energy are startling in the future China.

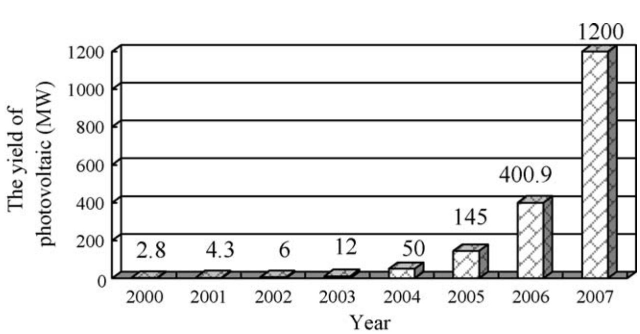


Fig. 9. The yield of solar cell in the past 8 years (source: CDIC and news).

3.3. Solar–wind hybrids energy

As mentioned above, the solar energy and wind energy in China are abundant, and which have been utilized in some domain, such as lighting system of city, water pumping and generating power station. The applications of stand-alone wind energy or solar energy have improved the living quality of remote villages' people, and the earning of family is increasing by using the electric power, and more and more ordinary people of remote zone realized the enormous change of Chinese society in every corner. However, a common drawback existed in the stand-alone wind energy and solar energy generating power system, which is the unpredictable output electric power, and the output power depends on the unpredictable weather and climatic changes.

Fortunately, the hybrid system can partially overcome the problems. The hybrid system is integrated in multifold resources in a proper combination. Some hybrid methods have been used in order to ensure the quality of electric power in Chinese remote zone, i.e. the diesel–wind, diesel–solar and wind–solar hybrid systems. However, the widespread use of diesel generators has a threat to the environment, and soil pollution and groundwater pollution occur when diesel spills take place. The environment of Chinese west zone is very brittle and the traffic is not convenient in large remote villages. With the rapid rise in energy price, the price of diesel oil is not withstood by the poor economy situation of west zone. The only way to solve this sustainability problem is to consider renewable energy resources. Solar energy and wind energy are the most abundant renewable energy resources in China, and very good compensation characters are usually found between solar energy and wind energy. The good solar irradiation and poor wind energy are provided in the summer, whilst a relative good wind energy and poor solar irradiation occur in the winter. The daytime has high solar irradiation and poor wind energy, whilst the night has relative good wind energy when the solar irradiation is almost zero. The strength of one source is used to overcome the weakness of the other in a wind–solar hybrid system, which has better competition and is more popular. Consequently, the hybrid system is greatly enhanced by the load demands at all times, and the higher generating capacity factor is achieved by combining wind energy and solar energy with a storage technology to overcome the unpredictable output electric power [38–41].

Wind–solar hybrid energy system is more and more considered in China as a renewable energy resource compared to conventional stand-alone wind energy system and solar energy system. There are many applications for directing wind–solar hybrid system, and the most extensive utilizations are the city road lighting and distributed generation and water pumping. Especially, with the rapid rise of the energy price, the application of wind–solar hybrid system is accelerating, and the great environmental and economic benefits have been brought by using the hybrid power system. Some hortative policies are formulated by the central government and operated in the whole nation. Hundreds of manufactories have produced millions of wind–solar hybrid equipments in the past 5 years. Fig. 10 shows a conventional stand-alone wind–solar hybrid system topology, which contains: a wind turbine, a permanent magnet generator, a diode bridge rectifier, a solar cell, three DC/DC converters, a DC/AC converter, a storage battery, a control unit, sample circuits and a DC load and an AC load. According to a different load, the DC/DC converter II and DC/AC converter is used to convert the electric power, respectively. And the sample circuits of voltage and current are used to calculate the maximum output power using the Digital Signal Processing (DSP), and four control pulses are emitted to control the pulses of MOSFET. The alternating current (AC) and direct current (DC) generate using DC/AC and DC/DC converters, respectively.

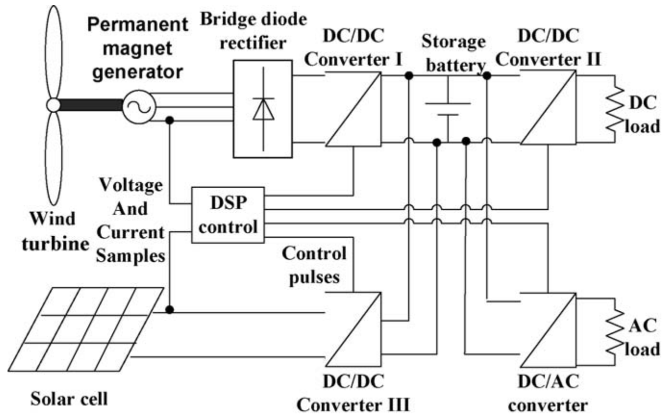


Fig. 10. The conventional topology of stand-alone wind–solar hybrid generating system.

At present, there are some problems to puzzle the development of hybrid system. They are as follows: (I) the Maximum Power Point Tracking (MPPT) control method is a difficulty problem to improve the efficient of hybrid system, some intelligent control method must be used to improve the conventional PID controller, such as Fuzzy, Nerve Network (NN), Immunity and Robust. (II) The efficient MPPT algorithm must be considered to increase the output efficiency of hybrid generate system. It contains the MPPT of wind turbine and the MPPT of photovoltaic, such as the perturbation and observation (PO) method and the incremental conductance (IC) method and the constant voltage (CV) have been used to the hybrid system. Although various methods of MPPT method have been proposed in existing literature, the power generate efficiency is relative low, and the amount of electric power generated by hybrid system is always changing with weather conditions. (III) The circuit topology must be regarded to acquire the maximum power point (MPP). The conventional Buck and Boost and Bust-Boost circuit are used in the hybrid system, but the efficiency is low during the acquire MPP course. (IV) The management of storage battery must be considered, and this contains the charge and discharge management. (V) The matching and optimization of hybrid system must be considered to increase the benefit and decrease the investment.

4. Hybrid generating system applications in China

In China, the main wind–solar hybrid system is used to the city road lighting and distributed generation and water pumping for irrigation. Especially, with the rapid rise of the energy price, wind–solar hybrid energy application still has great potential in China.

4.1. The city road lighting system

It is well known that China is the largest developing country in the world, and the population is beyond 1.3 billion at present. Hundreds of big cities lie in the large soil, and the population is more than a million. There are more than 10 million street lamps in those cities. For instance, a street lamp consumes two degrees of electric power everyday, and the annual total amount of electric power is more than 730 degrees. The annual total amount of whole city road lighting system is more than 7.3 billion degrees. The expense of electric power is more than one billion dollars. The enormous burden of economy is supported by the Chinese government, and the abundant primary resource is consumed at the time. Fortunately, the problems have been considered by the Chinese central government. The wind energy and solar energy are utilized in the city road lighting system by some local governments, i.e. wind energy street lamp, solar energy street lamp and wind–solar hybrid energy street lamp. The wind–solar energy street lamp has better competition and is more popular. More and more cities in China begin to replace the conventional street lamp by the wind–solar hybrid energy street lamp [37–39].

At present, a hybrid LED lighting system contains a solar cell and a wind turbine and storage battery, the capacity are 150 W and 400 W and 200 Ah, respectively. The total price of hybrid LED Street lamp in China is 25,000 RMB compared with the price of conventional street lamp 15,000 RMB. In an example of city with 50,000 conventional street lamps located in the east of China, the annual total of electric power is more than 66 million degrees, and the annual expense is more than five million dollars. The total purchase cost of conventional street lamp is 0.107 billion dollars. The total expense for government is more than 0.27 billion dollars during 20 years. The total wastage amount of coal is more than 396,000 tons at the time. In case of the lamps, the conventional street lamp was replaced with the wind–solar hybrid street lamp. The total purchase cost of wind–solar hybrid street lamp is 0.1429 billion dollars and total expense of electric power is zero. Synchronously, the total wastage amount of coal is zero. Certainly, the battery is replaced three times during 20 years, the total cost is 0.1286 billion dollars. The annual cost of maintenance is one million dollars. The total cost of wind–solar hybrid street lamp is approximately 0.2915 billion dollars during 20 years. To date, the cost of wind–solar hybrid street lamp is more than the conventional street lamp, but the environment benefit is big. The wind–solar hybrid street lamp has become competitive and will be more popular in future China. At present, the technologies are absent in China, such as MPPT control method, MPPT algorithm and management of the storage battery. More and more Chinese specialists have regarded the problem in the recent decades, and some mature technologies have been used to the industry productions. Certainly, the technology grade is low compared with the developed country. For instance, great deals of overseas MPPT algorithms are used to the large industry zone by Chinese specialists, but the domestic technology has a little share.

Some other actual applications of wind–solar hybrid street lamp are used in China, such as the freeway lighting system, city community lighting system and scenery lighting system. However, the holding rate of wind–solar hybrid street lamp is less than the conventional street lamp at present. The wind–solar hybrid street lamp still has great potential in future.

4.2. Distributed generation (DG)

In 2008, two big natural disasters occured in south and middle of China, respectively. In January, a big storm attacked the south of China, and more than fifteen provinces and 0.5 billion populations were affected by an abrupt storm. The supply of electric power was stopped because of the coal of north of China was not transported to the south, and the water supply was stopped because of the suspension of electric power. As mentioned above, millions of people lives were out of gear. On May 12, 2008, an incredible earthquake occured in the beautiful Wenchuan city of Sichuan province, located in the middle of China. More than ten million populations are affected by the big natural disaster, and the stricken area is more than 100,000 km^2, and millions of people lose their relatives, their parents, lovers and children. The electric power and the water supply are simultaneously stopped by the fatal destroy of earthquake. When millions of people run into big suffering, a big issue shows that the distributed electric power generating system is absent in China. The electric power has been commonly generated in large power plants operating in a central

location and transmitted to consumers via transmission and distribution networks. The large scale distribution network (LSDN) is considered by Chinese government in past 30 years, and the accumulative total amount of electric energy in 2005 is 517184.8 MW. However, a big danger exists in the LSDN when the people more and more depend on the electric power supply. Millions of people will be affected by an electric net accident, the factory production and the society movement are stopped when the power is cut by the unpredictable accident.

The Chinese government have realized the importance of DG in order to settle the problem during the unpredictable disasters. The lash-up electric power can be generated by using the micro-diesel. However, the method is achieved with difficulty when the disaster happened because of the traffic is stopped and the disaster area does not have adequate diesel oil. Fortunately, the wind energy and solar energy are not affected in the natural disaster. With the development of technology, a wind–solar hybrid system can partially overcome the problems. The hybrid DG have some merits, such as efficient, reliable, environmentally friendly, and the origin of electric power is renewable and easy to distribute abroad. The distributed energy generation means that energy-generating units are situated close to energy consumers, and the small hybrid DG units will rapidly develop in the foreseeable future. Chinese government have invested 0.7 billion dollars to establish 268 small water power plants and 721 stand-alone wind–solar hybrid power plants from 2002 to 2005, and the beneficial population is more 1.3 million people in west provinces [38].

In an example of no watch transformer substation and railway station in Tibet. In 1st July 2006, the Qingzang railway was established from Xining of Qinghai province to Lhasa of Tibet by thousands of worker, and the length is 1956 kilometers, where execrable environment and far-flung winter [42] prevail. However, transformer substation and railway station are established on the way because of the train movement needs electric supply, and the voltage grade is 110 KV. Based on the execrable environment, the transformer substation and railway station are established no watch, and the total is more than 38. Certainly, some obligatory technologies are used to the no watch transformer substation and railway station, such as image stakeout, remote control, fire protection, alarm, long-distance transfer and Wide Band. Tibet has the highest irradiation in China, and the mostly hungrys zones have a great prospect to utilize photovoltaic generation. These technologies have improved the automatic level of DG [43–44].

Some other actual applications of DG have been used in China, such as the camping lighting system, lash-up lighting system, mobile vehicle of power supply and spare power supply. Especially, millions of cattle farmers working in the widest northwest zone of China, the herd and cattle farmer will move with various seasons. The browse zone is far away from main power lines, and conventional electric power is no practical. Fortunately, they can conveniently gain the electric power by using the small hybrid DG units, and the life of cattle farmer can be improved by using electric appliance. However, the share of DG is small at present. With the improvement of people's life, more and more people and Chinese government have realized the importance of DG to improve the security of electric power supply, and the wind–solar hybrid DG has great potential in future China.

4.3. Water pumping for irrigation

China has abundant water resources in large soil, according to the data of irrigation works department, the annual total amount of earth's surface water is 271.15 billion m^3, and the total amount of ground water is 82.88 billion m^3. However, the average amount of Chinese people is less than 2.7 thousand m^3, and the share is only 1/4 compared with the average amount of world [45]. Especially, the water is exceedingly lacking in the northwest zone of China, and the desert zone of northwest China in 2007 is more than 1.3 million km^2. Based on the data of Chinese forest bureau, the annual increscent desert area in 2001 is more than 2000 km^2 [46–48]. Fortunately, Chinese central government and local government have realized the problem of increasing desert area, and some actual actions have been implemented to improve the environment and zoology of northwest zone.

It should be mentioned that in the past 30 years, Chinese people have planted a mass of trees, and the total amount of tree is more than 30 billion. The environment and zoology of China have great improvement in the past 10 years. However, as we can see from the news, billions of trees are dead because of lack of water. Fortunately, the groundwater of desert zone is abundance in Chinese northwest zone. The ground water gives a hope to banish the desert. Some electric power is used to pump groundwater by using water pump. As mentioned above, the environment and zoology is very brittle, and the desert zone is far away from main power lines, and the traffic is not convenient. Simultaneously, the high solar irradiation and wind energy exist in the large northwest zone. The wind–solar hybrid water pumping has great potential to banish the desert and improve the irrigation area of northwest farmland [49,50].

The solar water pump has been used to pump ground water in the west of China. For example, a hybrid system of solar water pumping for irrigation and lighting has been installed in Shihezi of Sinkiang province and the capacity of photovoltaic is 2.5 kW. The data of experiment indicated that the average total of pumping water is 60 m^3, and the biggest amount is 80 m^3 under high irradiation conditions. The system settles the problems of irrigation and lighting in remote villages. According to the data of World Bank, the water price of solar water pump is equal to the diesel pump under the system power is 40 kW conditions. At present, with the decreasing price of solar cell, the system power is about 75 kW. If the price of solar cell decreases three dollars per watt, the system power will achieve from 150 kW to 200 kW. So with the development of photovoltaic technology, the solar water pump has a great prospect in future. Certainly, the beautiful future is based on the advancement of technology, such as solar cell, MPPT, converter, inverter, motor and water pump [49]. However, a prominent weakness exists in the stand-alone solar system, which is that the system could not work full time because the output power of solar water pump is varying with the change of irradiation. An easy method can settle the problem, which is the wind–solar hybrid system. Solar energy and wind energy are the most abundant renewable energy resources in west of China, and very good compensation characters are usually found between solar energy and wind energy. The pumping ground water total of wind–solar hybrid system is more than the stand-alone solar water pump. The potential of wind–solar hybrid water pump system is large in future west zone, which can improve the zoology and environment and life quality of common people in remote villages of west zone.

Some actual applications have been used to improve the zoology of northwest and traffic, such as the desert road, protect desert oasis and solidify desert. For instance, The Talimu desert road is laid to link the north of Xinjiang province and the south in 1995, which is located in the biggest Takelamagan desert of China, and the length of desert road is more than 550 kms [51]. In both sides of desert road are planted millions of foliage, and the drop-irrigation technology has been used to pump ground water using diesel electric power. The wind–solar hybrid generating power system will replaces the conventional diesel generating power system in the foreseeable future. More than five desert roads have

been achieved in the last 20 years, with the development of desert road and the increase of foliage, the need of hybrid system is big in large west zone.

5. Renewable energy policy and barriers in China

The renewable energy has been considered by the Chinese government in the past 10 years, and the Chinese Renewable Energy Law had been confirmed by the Chinese government in 28 February, 2005. According to the data of CDIC, the object of renewable energy development in 2020 contains the following: the large water electric power is 0.3 billion kW, wind energy is 30000 MW, solar energy photovoltaic generating system is 1800 MW, the biology energy is 30000 MW, solar water heater is 0.3 billion m^2 and the biology fuel is 15 billion liters [32].

In order to achieve a sustainable development goal, the Chinese government formulates a series of policies and regulations to encourage renewable energy utilization, such as the price of wind electric power is approximately double when compared with conventional electric power, and the renewable energy lighting is applied to city road lighting system by some local government authority [53,54]. However, there are more than thirty provinces in China, and the impetus of applying renewable energy is different in various provinces. For example, the development velocity of Shanghai zone is the most quick in China, compared with the west provinces, Shanghai lacks the fossil resources, and Shanghai local government considers the development of renewable energy, such as sea wind, solar energy and tide energy. On the contrary, some west and north provinces have enough fossil resources, the impetus is small. Furthermore, the policies and regulations of the central government are rejected by Local governments [52–57].

In the past 10 years, Chinese renewable energy applications have gained very big achievement, and the technology of renewable energy is improved in every domain. However, some barriers embarrass the rapid development in China, such as policy barrier, financial barrier, market barrier, and technology barrier.

Firstly, the hortative policy has been established by the central government, but the policy is difficult to be implemented by local government. Little substantive action has been taken for the renewable energy development. Secondly, the renewable energy is in need of abundant money, and the price of renewable energy manufacture is more than conventional ones, which is more than the sufferable bound of ordinary people. Especially, the purchasing power of west people is very poor, and it is impossible to purchase the costly wind–solar hybrid generating power system. In other words, the financial help of government is necessary in order to implement economic sustainable development. Thirdly, the market is small in the renewable energy application. For example, the total yield in China of solar cell in 2007 is 1200 MW, and the share of solar energy is of 35% in whole world, which ranks first in the world. However, a little share of solar cell is used to the domestic solar production and the most shares are exported to the developed countries. Finally, the technology of renewable energy is gripped by the developed countries, and the technical investment is not enough in that it is impossible to exploit the pivotal technology.

6. Conclusion and recommendations

It is well known that China has abundant renewable resources, and this paper presents the distributing and development and application in China. With the rapid development of Chinese economy, the hortative policy is established by government, and it can be predicted that the utilization of renewable energy and the production of renewable energy will rapidly increase due to more and more energy pressure in future. Consequently, the central government and local governments have realized the important of renewable in order to achieve the sustainable development. Furthermore, the purchasing power of ordinary people is rapidly increasing with the booming development of Chinese society, and more and more ordinary people realize the importance of environment. The potential of renewable energy application in China is large in the foreseeable future.

Wind energy and solar energy in China are abundant in large soil, and renewable energy from wind and solar are the most environmentfriendly energy. However, the output power of stand-alone wind energy and solar energy system depend on the unpredictable weather and climatic changes, and the output power is not going steady. The wind–solar hybrid system can partially overcome the problems. Some productions of hybrid system have been utilized in China; the hybrid lighting system has been used to city road lighting by hundreds of Chinese cities. The competition of hybrid system is increasing in the past 10 years, and which is more and more popular. It is predicted that the wind–solar hybrid system has a big potential in future China.

However, although the Chinese central government has established some hortative policies and laws, the obvious policy barrier and economy barrier and technology barrier and market barrier for the wind–solar hybrid system are in existence. The government's strong financial support is important to settle the barriers. In order to achieve the sustainable development, the following measures are especially recommended in this regard [38–39,58–60]:

1. The applications of wind–solar hybrid energy are promoted by the hortative policy of central government and local governments.
2. Abundant fund should be launched into the research of wind–solar hybrid energy, and the universities and graduate schools should be encouraged to research in wind–solar hybrid energy system.
3. International cooperation should be encouraged to improve the domestic technology by central government and local governments.
4. The central government should provide enough funds to help the remote villages' end users of northwest zone in future.
5. The tax reduction/exemption will motivate the enthusiasm of entrepreneurs, and which will increase the market through policy initiatives.
6. The advantage of investors should be ensured by government policies.
7. The large desert grid-connect power plant must be established to improve the energy structure in the foreseeable future.
8. The industry chain should be established in order to enhance the economy benefit of Chinese photovoltaic industry. Especially, the lack of silicon material should be settled in future.
9. The attestation and detect organization lacks the contact with the international organization, and the criterion of whole industry is not be established.

Acknowledgments

This Project was granted financial support from Chinese Postdoctoral Research Foundation (No: 2005038435), Shanghai BaiYuLan Science and Technology Foundation (No: 2007B073), and China Education Ministry Research Foundation (No: 20071108) and Science Research and Development Program of Shanxi province (No: 200811026).

References

[1] CDIC. The consumption amount of oil is 0.35 billion tons. http://www.ce.cn/cysc/ny/shiyou/200707/17/t20070717_12193884.shtml [accessed 03.06.08].
[2] The import amount of oil is excessive speed in China. http://www.build.com.cn/hangyedongtai/ShowArticle.asp?ArticleID=2020 [accessed 03.06.08].
[3] Chinese coal output amount in 2007 increases 8.2% compare with 2006. http://www.3jjj.com/coal_new.asp?nid=381831&lid=44 [accessed 03.06.08].
[4] Chinese let amount of SO_2 in 2005 ranks the first in the world. http://news.sina.com.cn/c/2006-08-04/11289660143s.shtml [accessed 03.06.08].
[5] The share of primary energy in Chinese total energy consume. http://finance.sina.com.cn/roll/20080409/02202131646.shtml [accessed 03.06.08].
[6] The bulletin of Chinese photovoltaic industry in 2005. http://www.cres.org.cn/person_file/2007-11-30/20071130225127.html [accessed 03.06.08].
[7] The distribution zone of wind resources in China. http://www.crein.org.cn/view/viewnews.aspx?id=20080130165749765 [accessed 03.06.08].
[8] Liu W-K, Zhang Z-Y, Li Y-F. Wind energy and wind generating electric power technology. Chemistry and Industry Publishing Company; 2007.
[9] Wind resources of China. http://www.newenergy.org.cn/html/0039/2003991.html [accessed 03.06.08].
[10] The average power density of wind energy in China. http://cwera.cma.gov.cn/upload/b_2_left_02.jpg [accessed 03.06.08].
[11] The distribution of wind energy and oil-gas in China. http://bbs.godeyes.cn/Announce/Announce.asp?BoardID=302&ID=266426 [accessed 03.06.08].
[12] The large foreground of wind generating electric power. http://www.crein.org.cn/view/viewnews.aspx?id=20080602101049874 [accessed 03.06.08].
[13] The rank of new wind energy capability of world in 2006. http://www.crein.org.cn/view/viewnews.aspx?id=20080410132832663 [accessed 03.06.08].
[14] The increasing status of Chinese wind turbine from 2000 to 2007. http://www.crein.org.cn/view/viewnews.aspx?id=20080410103149351 [accessed 03.06.08].
[15] The capability Statistic of Chinese wind turbine in 2006. http://www.crein.org.cn/view/viewnews.aspx?Id=20080410103544304 [accessed 03.06.08].
[16] The new capability of Chinese wind energy in 2007 ranks the third in the world. http://www.jxcad.com.cn/simple/index.php?t525091.html [accessed 03.06.08].
[17] The current status and development of Chinese wind electric power. http://www.crein.org.cn/view/viewnews.aspx?id=20080410103830398 [accessed 03.06.08].
[18] CDIC. The total amount of Chinese generating electric power in 2005 is more than 0.5 billion kW. http://news.xinhuanet.com/fortune/2005-09/13/content_3482981.htm [accessed 03.06.08].
[19] China will become the important wind energy market. http://tech.sina.com.cn/d/2007-10-18/08291799958.shtml [accessed 03.06.08].
[20] The capability status of Chinese wind energy. http://www.crein.org.cn/view/viewnews.aspx?id=20080410102424991 [accessed 03.06.08].
[21] Wind generating electric power in the electric power system. http://www.crein.org.cn/view/viewnews.aspx?id=20080410103944132 [accessed 03.06.08].
[22] The energetically development of renewable energy in China. http://www.bm.cei.gov.cn/allfile/46/20061025150444461 32.asp [accessed 03.06.08].
[23] The development bulletin of Chinese wine energy in 2007. http://www.greenpeace.org/china/zh/press/reports/wind-power-report [accessed 03.06.08].
[24] DEWI. China and USA and Spain will become the engine of wind energy development in whole world. http://www.crein.org.cn/view/viewnews.aspx?id=20080529104932415 [accessed 03.06.08].
[25] The largest wind farm in the world will be built at Jiuquan City in Gansu Province, China, and invest 12 billion US$. http://unn.people.com.cn/GB/14769/7144602.html [accessed 03.06.08].
[26] The largest wind farm will operate in September 2008. http://finance.sina.com.cn/roll/20050404/08341484427.shtml [accessed 03.06.08].
[27] The first offshore wind form in China. http://www.cnfrp.net/news/echo.php?id=18531 [accessed 03.06.08].
[28] Distribution of solar resources. http://www.crein.org.cn/view/viewnews.aspx?id=20080131100451953 [accessed 03.06.08].
[29] The distribution of solar resources in China. http://www.crein.org.cn/view/viewnews.aspx?id=20080410101805382 [accessed 03.06.08].
[30] The distribution map of solar resources in China. http://www.taiyanggonggong.com/news/content/2008/4/385.html [accessed 03.06.08].
[31] The distribution map of solar resources in China. http://cwera.cma.gov.cn/upload/b_3_left_02.jpg [accessed 03.06.08].
[32] Renewable energy bulletin in 2006. http://www.cres.org.cn/person_file/2007-11-15/20071115145248.html [accessed 03.06.08].
[33] The development status analyse of solar water heater industry. http://www.newenergy.org.cn/Html/0083/3270816304.Html [accessed 03.06.08].
[34] The solar cell yield of China ranks the first in the world. http://www.sxcoal.com/2008/04/07/91317/Article.html [accessed 03.06.08].
[35] The solar cell yield of world increase 56% in 2007. http://finance.sina.com.cn/roll/20080326/07272097843.shtml [accessed 03.06.08].
[36] The solar cell industry data of China and world in 2006. http://www.crein.org.cn/view/viewnews.aspx?id=20080410111720272 [accessed 03.06.08].
[37] The first street of wind–solar hybrid street lamp in Xiangtan. http://bbs.zzz4.com/viewthread.php?tid=356453 [accessed 03.06.08].
[38] The industry bulletin of photovoltaic in 2005. http://www.cres.org.cn/person_file/2007-11-30/20071130225127.html [accessed 03.06.08].
[39] The industry bulletin of photovoltaic in 2007. http://dssc.brchina.net/read.php?tid=2825 [accessed 09.06.08].
[40] The biggest photovoltaic plant in Chinese Shilin. http://news.yninfo.com/yn/jjxw/200806/t20080609_655437.htm [accessed 10.06.08].
[41] Yang HX, Lu L, Burnett J. Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong. Renewable Energy 2003;28:1813–24.
[42] The survey of Qingzang railway. http://baike.baidu.com/view/2580.htm [accessed 10.06.08].
[43] The no watch transformer substation in Qingzang railway. http://www.qh.xinhuanet.com/qztlw/2006-09/20/content_8084113.htm [accessed 10.06.08].
[44] The total of no watch transformer substation is 38 in Qingzang railway. http://www.gov.cn/jrzg/2006-06/19/content_314131.htm [accessed 10.06.08].
[45] Water resources in China. http://www.nhyz.org/yxx/jxzy/zy/zy61.htm [accessed 03.06.08].
[46] The desert area is more than 18.12% of the total country area in China. http://www.china.com.cn/chinese/huanjing/1245632.htm [accessed 03.06.08].
[47] Chinese desert and father desert. http://hi.baidu.com/fzcskycn/blog/item/bde112d8bd8cdf3632fa1cc4.html [accessed 03.06.08].
[48] The annual increscent desert area is about a county in China, http://news.enorth.com.cn/system/2001/12/14/000216752.shtml [accessed date 3 June 2008].
[49] The solar energy water pump is applied in remote community. http://www.handlers.cn/down/details.asp?id=217012 [accessed 03.06.08].
[50] The solar energy is applied in both sides of desert road to solidify sand and plant tree. http://www.handlers.cn/down/details.asp?id=217013 [accessed 03.06.08].
[51] The most and only long desert road in China. http://www.tianshannet.com.cn/special/content/2007-03/01/content_1710864.htm [accessed 03.06.08].
[52] The domestic solar energy market should start in order to develop the solar energy industry. http://news.gz.soufun.com/2008-05-26/1777171.htm [accessed 03.06.08].
[53] The grid-contact price of wind electric power of various provinces in 2007. http://www.crein.org.cn/view/viewnews.aspx?id=20080410111224038 [accessed 03.06.08].
[54] The electric power price of renewable energy generate electricity and expense of apportion manage. http://www.crein.org.cn/view/viewnews.aspx?id=20060104135508218 [accessed 03.06.08].
[55] The wind energy development of various provinces in 2007. http://blog.sina.com.cn/s/blog_4eee9abf01008tx4.html [accessed 03.06.08].
[56] The expert fund manage method of renewable energy development. http://www.crein.org.cn/view/viewnews.aspx?id=20060620141707078 [accessed 03.06.08].
[57] Li Z-S, Zhang G-Q, Li D-M, Zhou J, Li L-J, Li L-X. Application and development of solar energy in building industry and its prospects in China. Energy Policy 2007;35:4121–7.
[58] The think of wind turbine manufacturing development status in China. http://www.newenergy.org.cn/Html/0085/5290817781.Html [accessed 03.06.08].
[59] The instruct idea of quicken wind energy technology equip made in China. http://www.crein.org.cn/view/viewnews.aspx?id=20000212135448031 [accessed 03.06.08].
[60] The Chinese energy problem and policy challenge in future. http://www.crein.org.cn/view/viewnews.aspx?id=20080410103723851 [accessed 03.06.08].